GaN-BASED DETECTOR ENABLING TECHNOLOGY FOR NEXT GENERATION ULTRAVIOLET PLANETARY MISSIONS. S. Aslam[1*], G. Gronoff[2], T. Hewagama[3], S. Janz[4], C. Kotecki[5], [1,3,4,5]NASA, GSFC, Greenbelt Rd., MD 20771; [2]NASA, LaRC, Hampton, VA 23681; [*]contact author e-mail: shahid.aslam-1@nasa.gov.

Introduction: The ternary alloy AlN-GaN-InN system provides several distinct advantages for the development of UV detectors [1], [2] for future planetary missions. First, (InN), (GaN) and (AlN) have direct bandgaps 0.8, 3.4 and 6.2 eV, respectively, with corresponding wavelength cut-off's of 1550 nm, 365 nm and 200 nm. Since they are miscible with each other, these nitrides form complete series of indium gallium nitride ($In_{1-x}Ga_xN$) and aluminum gallium nitride ($Al_{1-x}Ga_xN$) alloys thus allowing the development of detectors with a wavelength cut-off anywhere in this range. For the 280-365 nm spectral wavelength range AlGaN detectors can be designed to give a 1000x solar radiation rejection at cut-off wavelength of 325 nm, than can be achieved with Si based detectors. For tailored wavelength cut-offs in the 365-480 nm range, InGaN based detectors can be fabricated, which still give 20-40x better solar radiation rejection than Si based detectors. This reduced need for blocking filters greatly increases the Detective Quantum efficiency (DQE) and simplifies the instrument's optical systems. Second, the wide direct bandgap reduces the thermally generated dark current to levels allowing many observations to be performed at room temperature. Third, compared to narrow bandgap materials, wide bandgap semiconductors are significantly more radiation tolerant [3], [4]. Finally, with the use of an (Al, In)GaN array, the overall system cost is reduced by eliminating stringent Si CCD cooling systems. Compared to silicon, GaN based detectors have superior QE based on a direct bandgap and longer absorption lengths in the UV.

Table 1. Si, InN, GaN and AlN photodiodes properties

Semiconductor	**Si**	**InN**	**GaN**	**AlN**
Indirect band gap, (eV)	1.12	-	-	-
Direct band gap, (eV)	-	0.8	3.2	6.2
Carrier concentration, n_i (cm^3)	$1x10^{10}$	206	$2.8x10^{-10}$	Near-0
ΔT for halving n_i (°K)	8.7	6.7	5.5	5
Reduction in n_i for ΔT = -30°K	15x	87x	2390x	685000x

Improved Dark Current Performance: Table 1 gives the band gap and intrinsic carrier concentration for Si, AlN, GaN, InN [5] and illustrates how the (Al,Ga,In)N semiconductors are expected to achieve significantly lower thermally generated dark current due to 10 or more orders of magnitude reduction in the intrinsic carrier concentration, even in the presence of a large difference in the effective recombination lifetime. Furthermore, the AlN-GaN-InN semiconductors exhibit an even stronger temperature dependence indicating that even moderate cooling will significantly reduce the dark current. Silicon, has the slowest recombination time (i.e. long carrier diffusion lengths), due to the near dislocation free epitaxial crystal growth techniques used in manufacture. Confined epitaxial growth of (Al,In)GaN is sufficiently mature enough to make the 10-12 orders of magnitude lower carrier concentration out-compete the faster recombination lifetime.

Improved Modulation Transfer Function and Spectral Quantum Efficiency: Both the Modulation Transfer Function (MTF) and the effective quantum efficiency are determined by the thickness of the (Al, In)GaN charge collection region (depletion region). The photodiodes in the array are designed to maximize charge collection efficiency. For a photodiode, the photocurrent is primarily due to the production of electron-hole pairs in the depletion region [6]. The photocurrent depends on the absorption coefficient, α, and in order to maximize this the depletion width should limit towards $1/\alpha$. For the wavelengths of interest (280-480nm), the (Al, In)GaN semiconductors exhibit high absorption, enabling a high quantum efficiency even when the absorption region thickness is an order of magnitude thinner than in a silicon device. The absorption coefficient for GaN is approximately 10 cm^{-1} greater for all the wavelengths of interest when compared to Si. Therefore the thickness of the active region of the device can be reduced without negatively impacting the QE while also having added advantage of reducing the dark current.

UV-Vis Spectrograph Focal Plane Array (FPA) Configuration: Figure 1 shows how a spectrograph can be configured with two 1M pixel arrays, AlGaN and InGaN, each hybridized to a radiation hard silicon ROIC. AlGaN arrays (for 280-360nm response) and InGaN arrays (for 365-480nm response) are grown by confined epitaxial growth on double-sided polished sapphire, see Table 2. The array is designed to be back-illuminated through the sapphire. Key to this development is the ability to grow (Al, In) GaN films using a "confined epitaxial" approach pioneered by NRL [7].

Goddard 1M Pixel AlGaN and InGaN Arrays: To date Goddard has carried out successful wafer fabrication runs to yield several good large format 1024-by-1024 AlGaN arrays with hexagonal pixels on a 18μm pitch, a SEM micrograph of a section of a good array is shown in Figure 2.

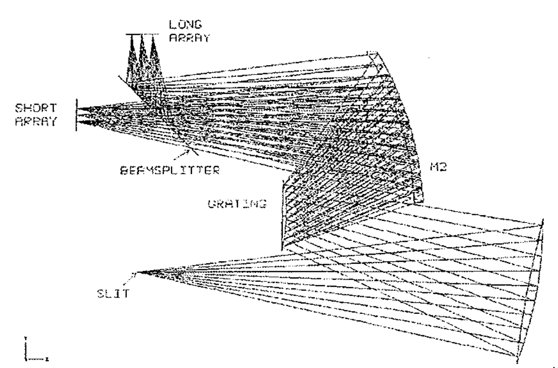

Figure 1. Spectrograph configuration

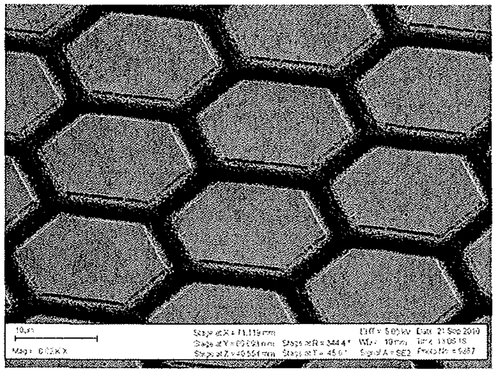

Figure 2. SEM micrograph of photodiodes fabricated using the confined epitaxy technique; the pitch is 18μm

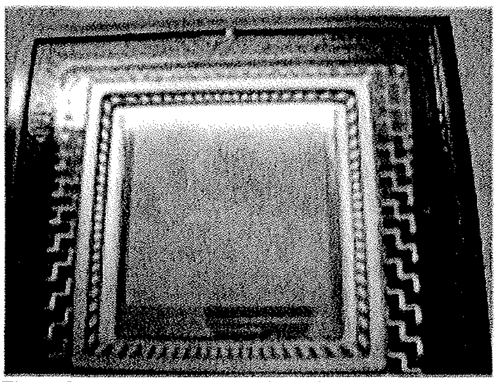

Figure 3. FLIR ISC0404 ROIC in package

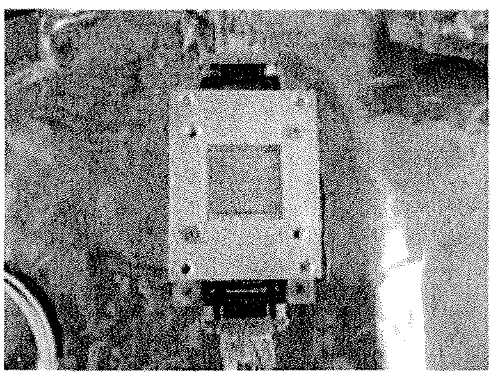

Figure 4. Hybridized array mounted on preamplifier and signal conditioning board

These arrays were fabricated from confined epitaxy material [7]. The p-i-n window composition, and measured dark current are shown in Table 2. The 1M pixel InGaN arrays are currently being processed. It is anticipated that by October 2012 these arrays will also be hybridized ready for functionality and radiometric testing in late November 2012. To date, two 1M pixel AlGaN arrays have already been hybridized to FLIR ISC0404 ROIC's, see Figure 3. The ROIC specifications are shown in Table 4. A picture of one of the packaged hybridized array mounted on a low noise preamplifier and electronic signal conditioning board is shown in Figure 4. The packaged array module is presently undergoing functionality tests at GSFC using Leach readout electronics. Once

Table 2. Spectrograph Channel 1 and 2: Array Specifications

Parameter	**Channel 1**	**Channel 2**
Spectral Band	280-365nm	365-480nm
Detector Absorber	AlGaN (47% Al)	InGaN (7.5% In)
Detector Pitch	18μm	
Array Configuration	1024 x 1024	
Dark current	< 1fA @ 0V	
Operating temperature	77K - 300K	
Response Non-uniformity	± 4%	± 4%
Operability	> 99%	> 98%

Table 3. Results from AlGaN test photodiode

WAFER	**#729**
AlN fraction in pin window, (%)	47
Unit cell	18μmx18μm
Test diode diameter, μm	120
Spectral response, nm	280-365
Dynamic Resistance, Ω.cm^2	2.3×10^{12}
Measured dark current @ 0V, (A)	$<1 \times 10^{-15}$
Computed dark current @ 0V, (A)	7.1×10^{-16}
Quantum efficiency @-0.5V, (%)	50 (expected)
Detectivity, D*, cm.√Hz/W	1.6×10^{15}
NEP, W/cm.√Hz	6.8×10^{-18}

functionality testing is complete the module will undergo radiometric testing for QE characterization.

Expected Performance: Assuming zero contribution from photon and background current shot noise, negligible $1/f$ noise and the observed leakage current is predominantly the dark current, then the noise equivalent irradiance (NEI) is given by $NEI = \sqrt{2qI_d \Delta f}/(A\eta q)$ ph/cm^2. With QE of $\eta = 50\%$ at $\lambda = 350$ nm, $\Delta f = 1$ Hz, $A = 1.13 \times 10^{-4}$ cm^2 and using the average dark current density measured at room temperature, $J_d = 8.5 \times 10^{-12}$ A/cm^2 (at -0.5V bias) gives $NEI = 219$ ph/s-pixel i.e. these photodetectors have a calculated sensitivity of 1pW/cm^2 [8]. The rms noise electrons on the dark current is $N_e = \sqrt{(I_d \tau)/q}$. For the dark current that we have experimentally measured, N_e is calculated to be about 55e$^-$. This detector noise threshold is higher than the read noise of the ROIC input circuit, $\approx 15e^{-1}$.

Future Missions: The proposed GaN-based detectors with low mass and power requirement, are radiation hard and with their high sensitivity performance will provide a technological breakthrough for space-borne UV spectrographs for the planetary community and could be part of the instrumentation payloads for future flagship missions, e.g. Uranus and future New Frontiers and Discovery missions.

References: [1] Razeghi, M., et al., *J. Appl. Phys.*, 79, 7433-7473, 1996. [2] Aslam, S., et al., *SPIE*, Vol. 5901, 59011J, 2005. [3] Ionascut-Nedelcescu, A., et al., *Trans. Nucl. Sci.*, Vol. 49, no. 6., 2002. [4] Aslam, S., et al., *Nucl. Instrum. And Methods in Phys. Res. A*, 539, 84-92, 2005. [5] Bougrov, V., et al., *Properties. of Advanced Semiconductor Materials GaN, AlN, InN, BN, SiC, SiGe*, John Wiley & Sons, Inc., New York, NY, 2001. [6] Sze, S. M., *Physics of Semiconductor Devices*, 2nd Edition, Wiley, New York, NY., 1981. [7] Eddy, C.R. Jr., et al., *Applied Physics Letters*, vol. 90, 162101, 2007. [8] Aslam, S., et al., *Electronics Letters*, Vol. 41, No. 14, 2005.